New LANL Facility for Coated Conductor Fabrication, Characterization and Applications

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Outline

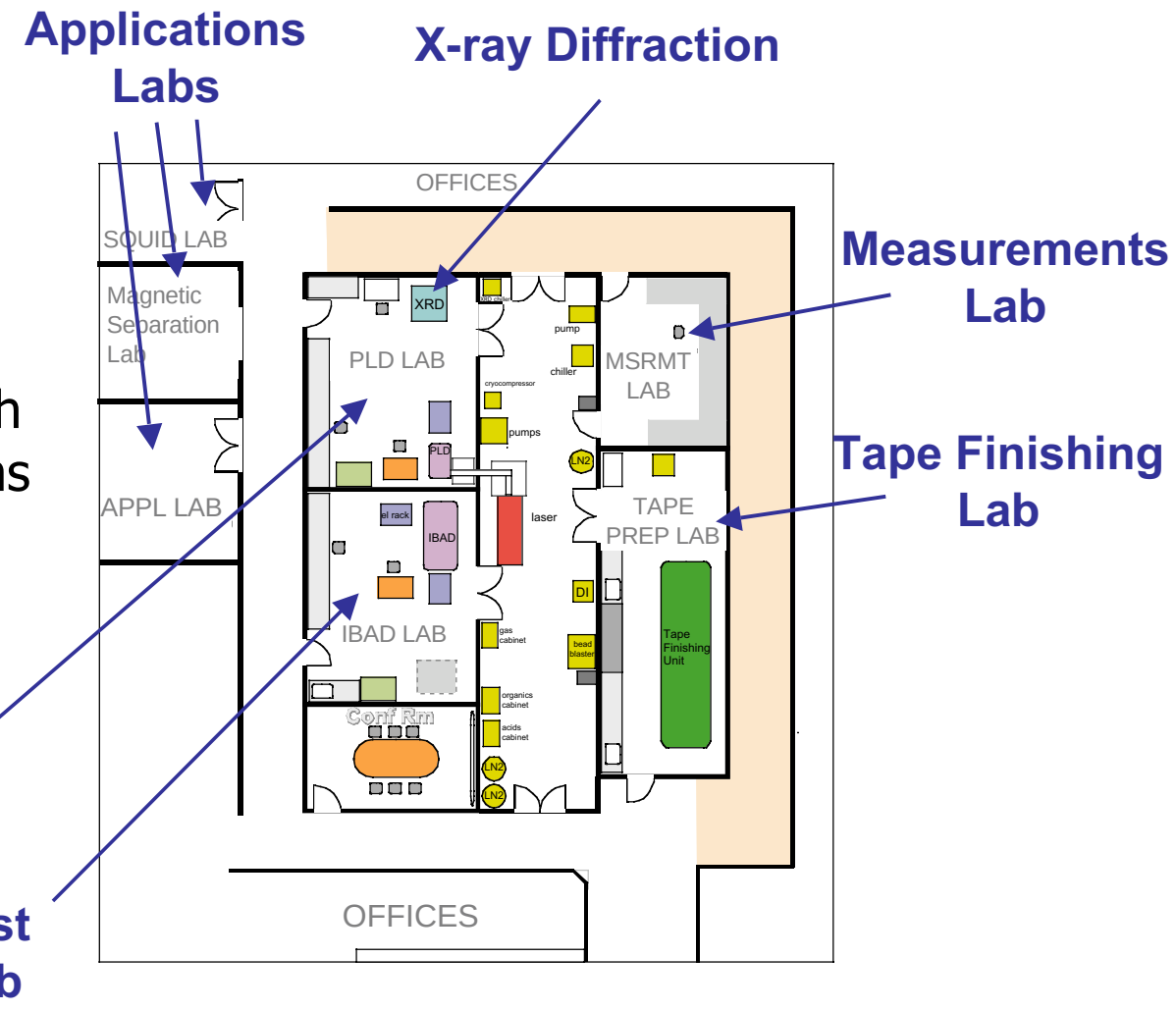
- Developments in the last year
- New capabilities: longer lengths and high-throughput experimentation
- Processes demonstrated: significant results obtained in the start
- ac loss measurements
- Summary

Accelerated Coated Conductor Development via the Research Park Facility

1) Scaled-up fabrication
   - Transition to production by industry
   - Longer samples available for analysis and applications
2) High-throughput materials experimentation
   - Test bed for new ideas
   - *In-situ* diagnostics
3) Increased interaction with partners
   - Co-location of outside partners
   - User facility, training
4) Applications testing lab
   - Lab with unique capabilities for evaluating conductors
   - Capability for testing prototype applications

STC Labs at the Research Park

- 4 new labs for Coated Conductor preparation and 3 for applications development
- CC preparation labs with reel-to-reel tape systems



Research Park - June 2001

Research Park - August 2001

Research Park: Oct. 2001 - Feb. 2002

Research Park: Oct. 2001 - Feb. 2002

Research Park - July 2002

IBAD Lab

IBAD template tapes on reels

PLD Lab

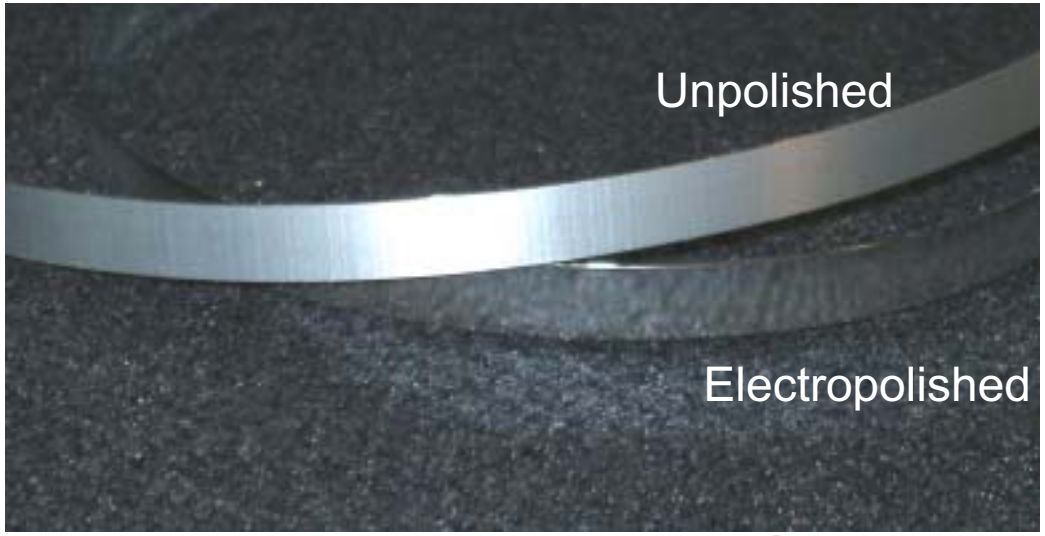
Working Labs at the Research Park

Accomplished:

- Metal finishing line: operational and producing tens of meters of tape with RMS surface roughness < 1 nm on 5 μm scans
- IBAD system: set up and producing meters of IBAD-MgO templates ($\Delta\phi \sim 12°$) on metal tapes
- PLD system: set up and producing superconducting YBCO films continuously on metal tapes
- Electrical characterization: demonstrated reel-to-reel setup

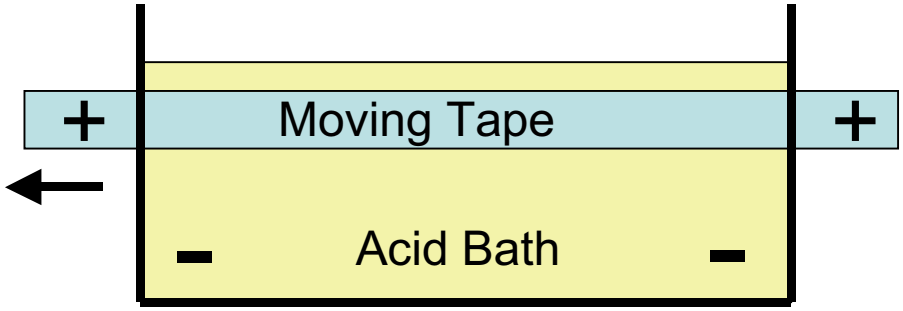
Tape Finishing

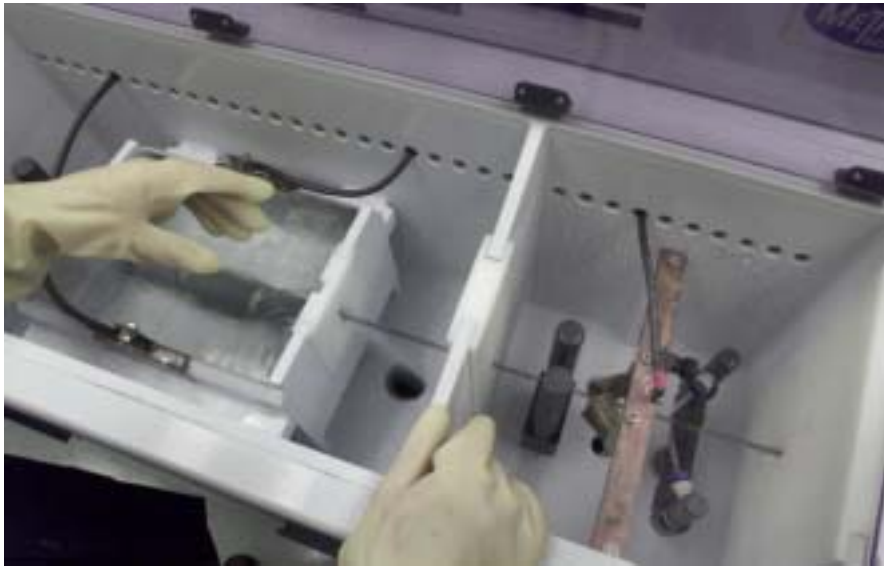
- Coated conductors require starting prepared metal tapes with smooth and clean surfaces
- New industrial-type equipment processes reels of metal tape by electropolishing
- Capable of reel-to-reel polishing of tape at high speed up to km lengths
- Capabilities for tape finishing research, including electroplating



Electropolishing cell

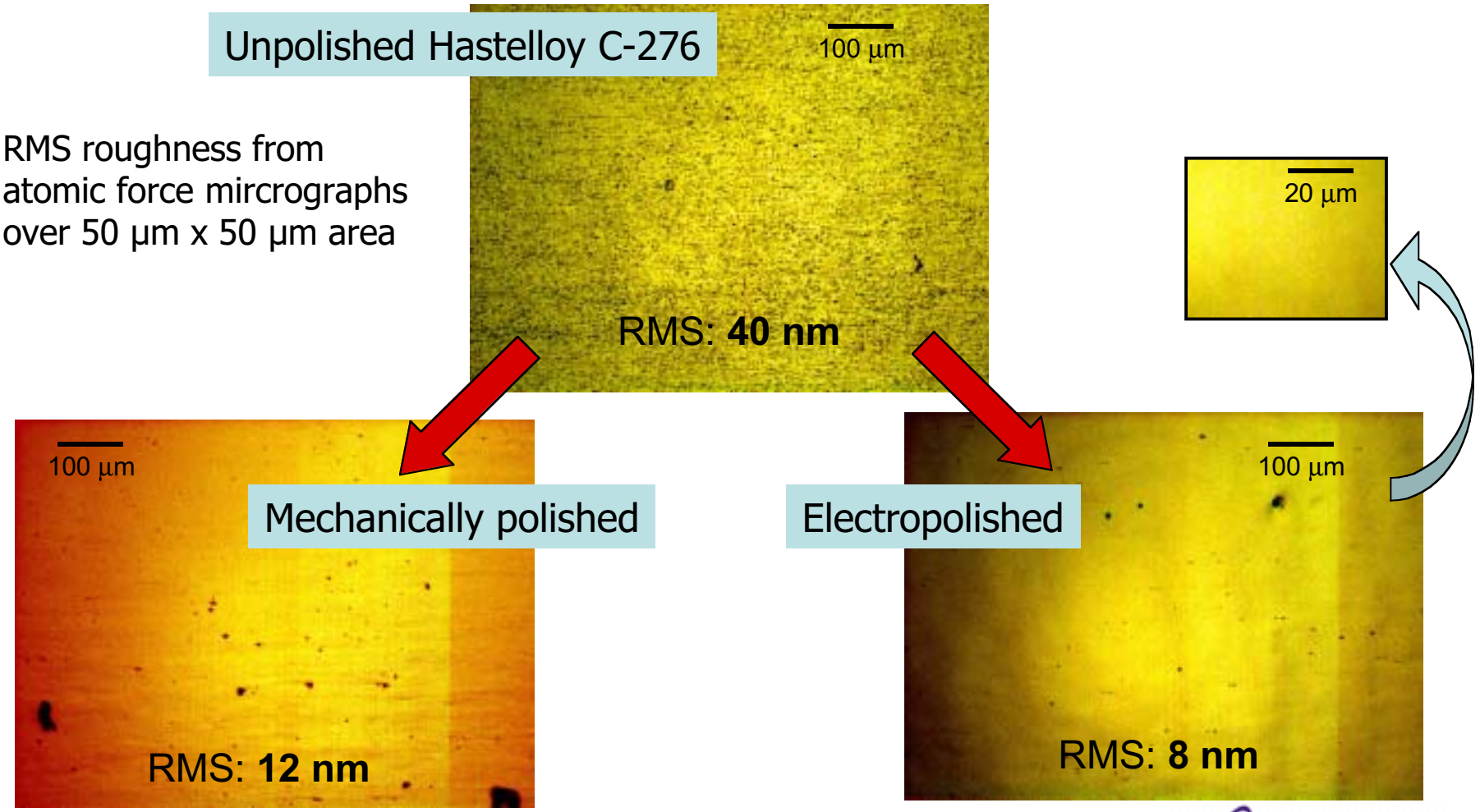
- tape speed: 15 - 30 m/hr
- voltage: 5 - 12 V
- current: 5 - 25 A





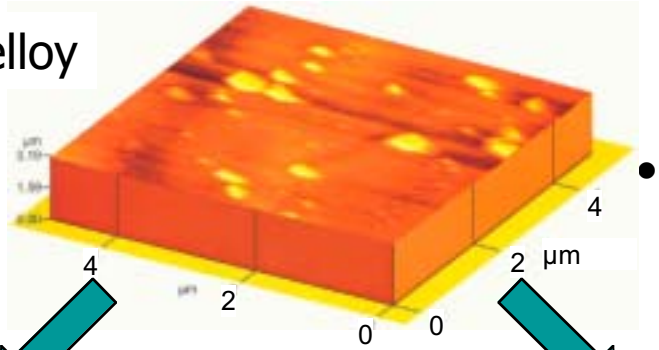
Results on Surface Smoothing: Optical micrographs

RMS roughness from atomic force mircrographs over 50 μm x 50 μm area



Fine Scale Surface Structure - AFM

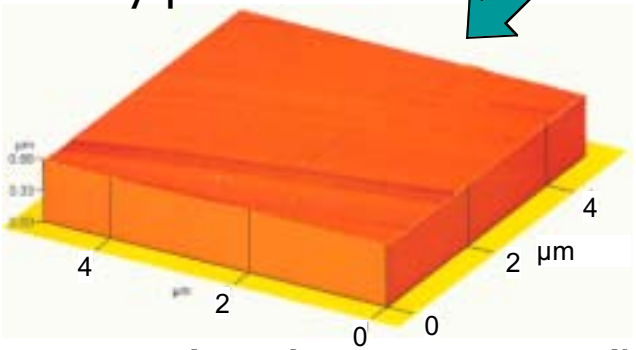
Unpolished Hastelloy



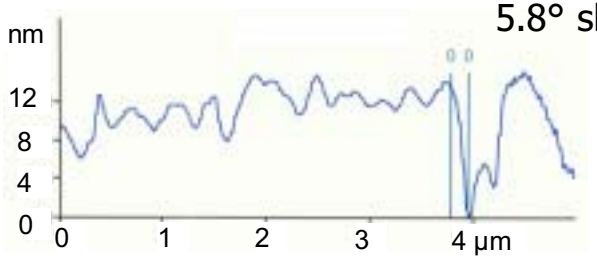
RMS roughness
(AFM 5 x 5 µm):

- 17 nm (avg.), 7 nm (line)

Mechanically polished

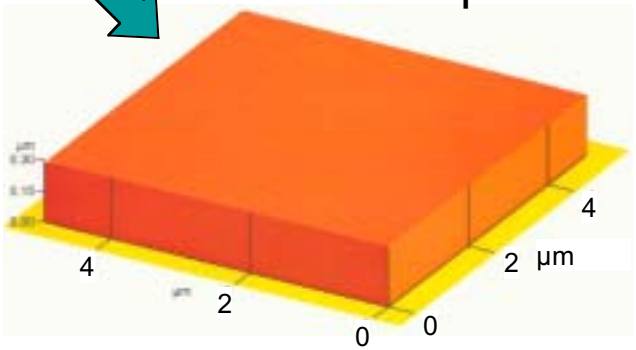


- 3 nm (avg.), 0.3 - 13 nm (line)

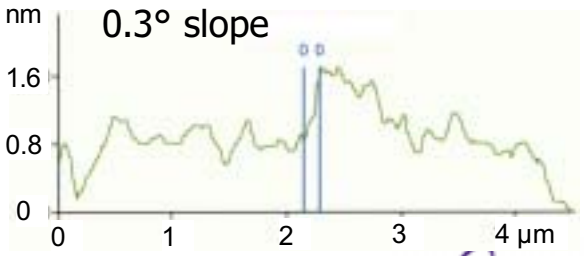


5.8° slope

Electropolished



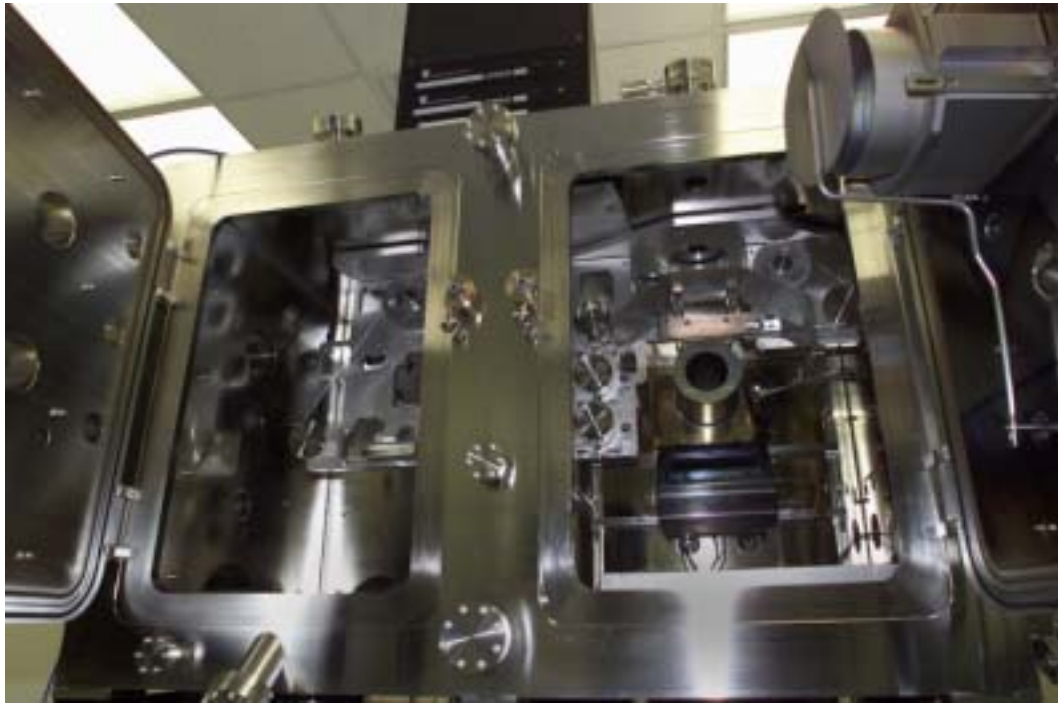
- 0.4 nm (avg.), 0.2 - 0.4 nm (line)



0.3° slope

Ion-Beam-Assisted Deposition Chamber

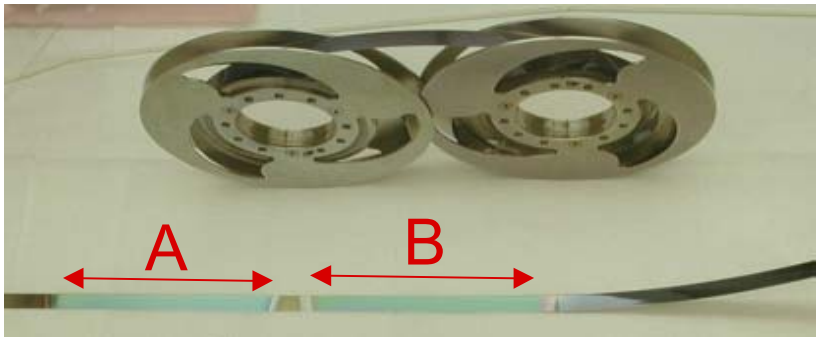
- Large vacuum chamber (6'x4'x3.5')
- Capability for process integration (IBAD and buffer layers)
- Reel-to-reel system provides for tape lengths over 100 meters
- 3000 - 6000 l/s pumping speed: < 2 hrs to pump, vent in 10 minutes: quick turnaround



Sequential Combinatorial Research from Continuous Tape Processing

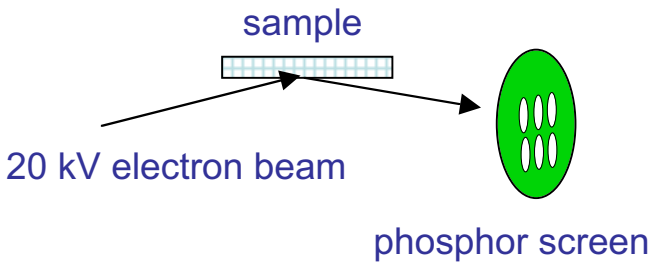
- Continuous tape processing is ideal for exploring process parameters in a sequential way
- We can track positions on tape from one process step to the next and develop a matrix of experiments (either continuously or in stationary batches)

A and B have different buffer layers on top of IBAD-MgO



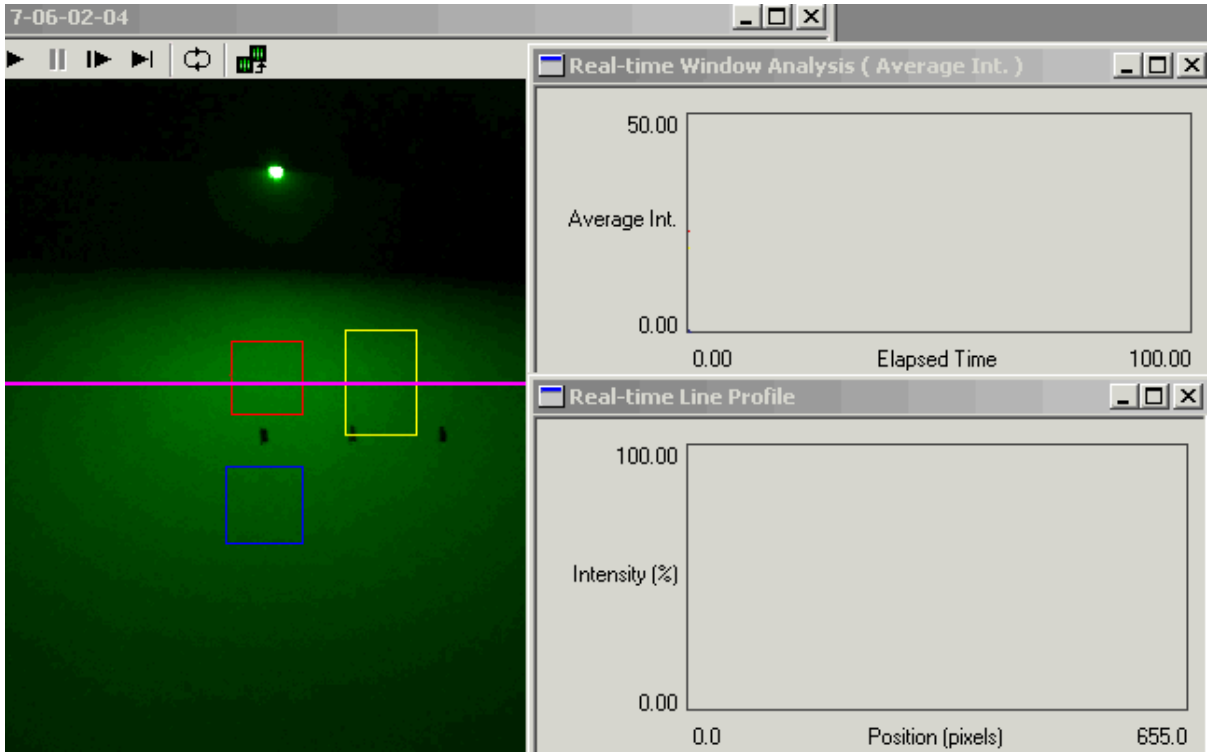
- Such combinatorial research provides for a high-throughput of experiments (100's of experiments in 1 reel) - *in-situ* evaluation
- Currently using this method for optimization of deposition processes
- IBAD process transferred successfully from Paul Arendt's lab to Research Park

In-situ RHEED is critical for development of the IBAD-MgO texturing process



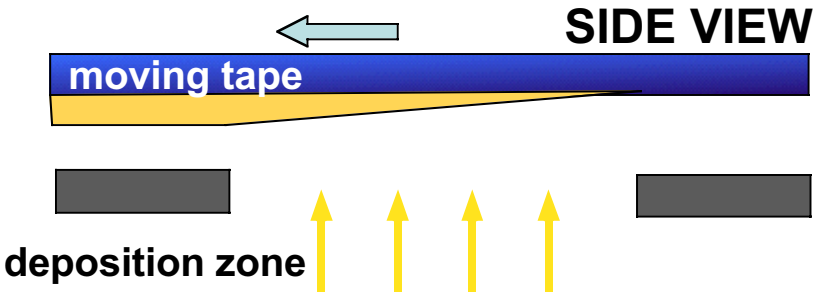
RHEED provides information on:

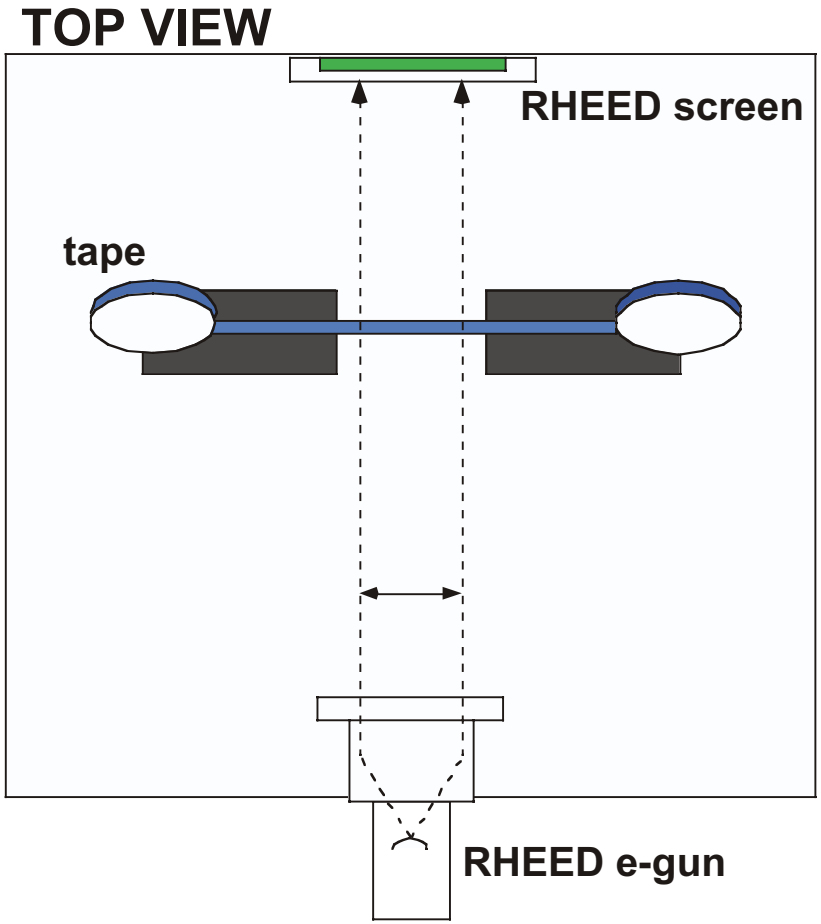
- Structure of film during growth (in real time)
- Texture development
- Optimum thickness (MgO)
- Out-of-plane crystallographic tilt
- Grain size



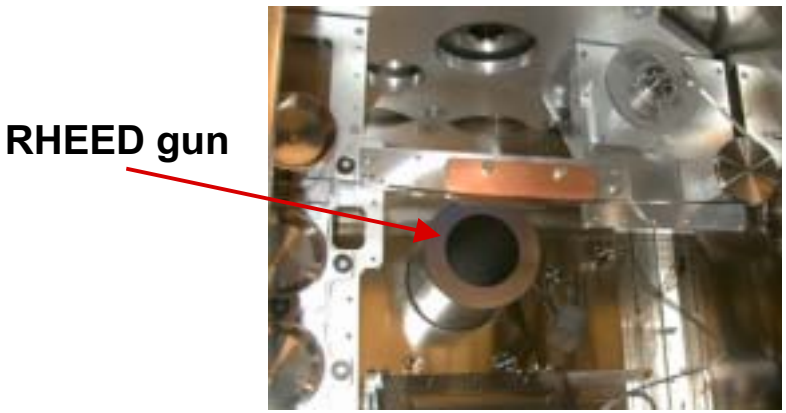
Real-time video of RHEED and diffraction pattern analysis IBAD-MgO on a stationary metal tape sample (k-Space software used for data acquisition)

Parallel Scanning RHEED for Continuous IBAD



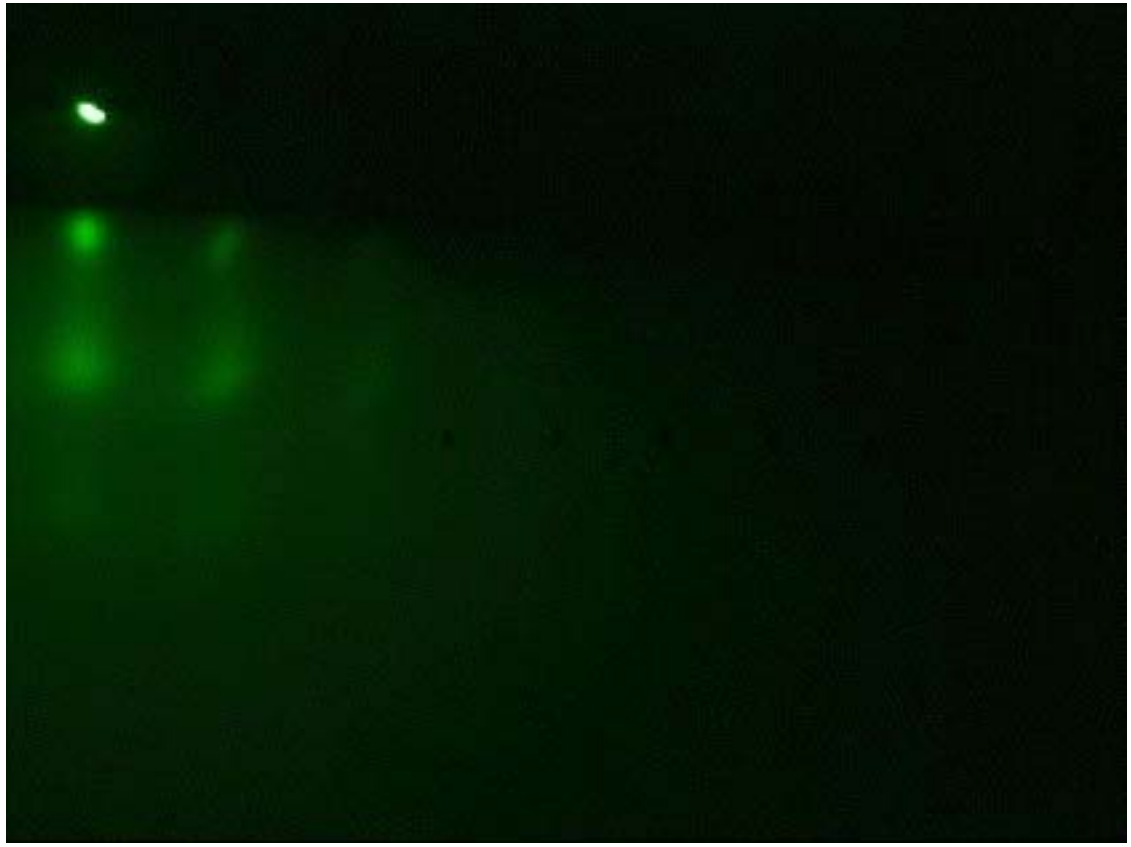


- By scanning the RHEED beam along the tape one obtains RHEED images at different stages of IBAD growth

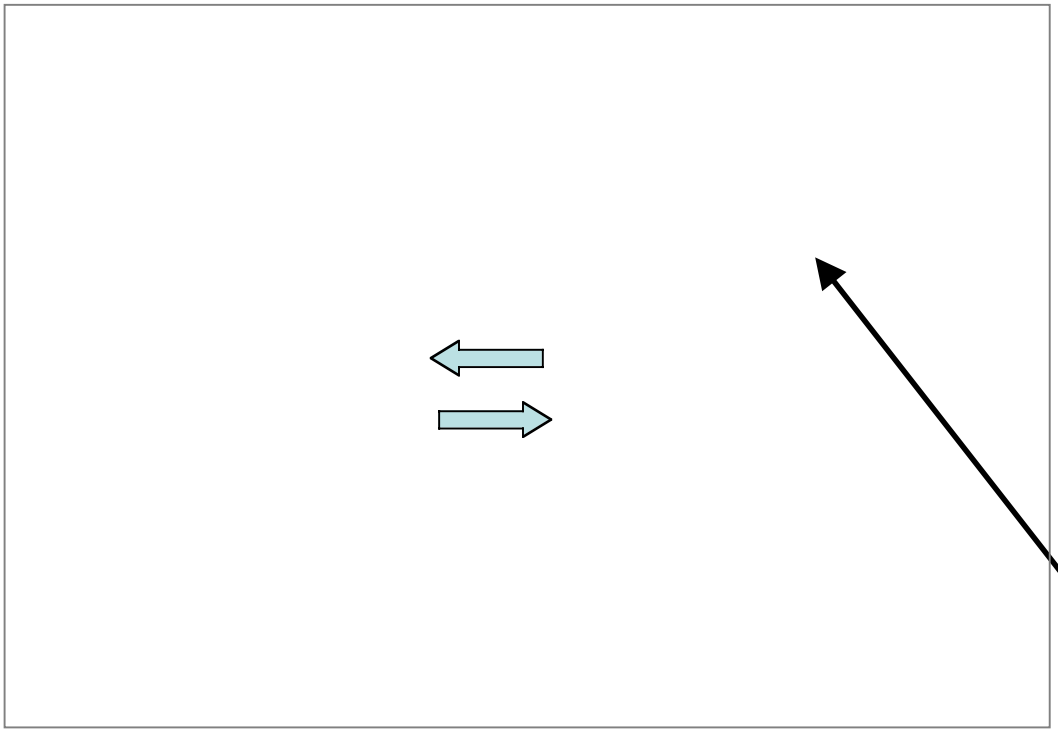


Parallel Scanning RHEED for Continuous IBAD

Tape moving



Tape moves back and forth for processing and quality control



IBAD station:

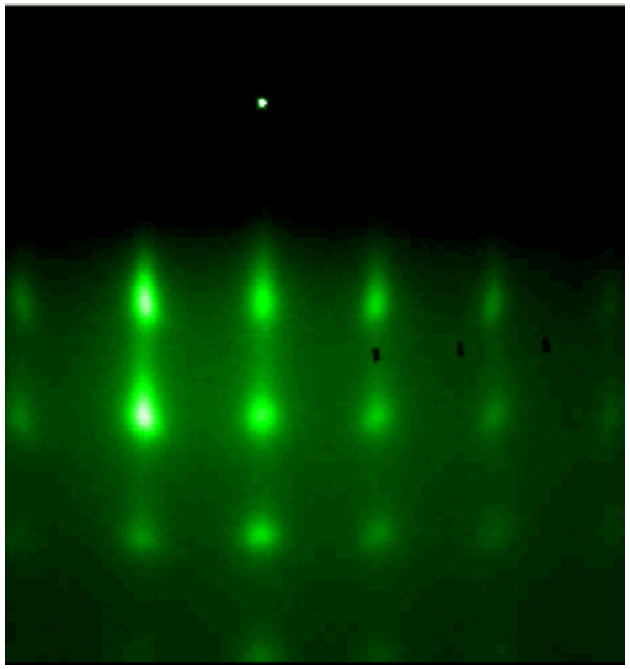
- Nucleation layer
- IBAD-MgO texturing

Buffer Station:

- Epitaxial-MgO
- Other buffer layers (YSZ, CeO_2)

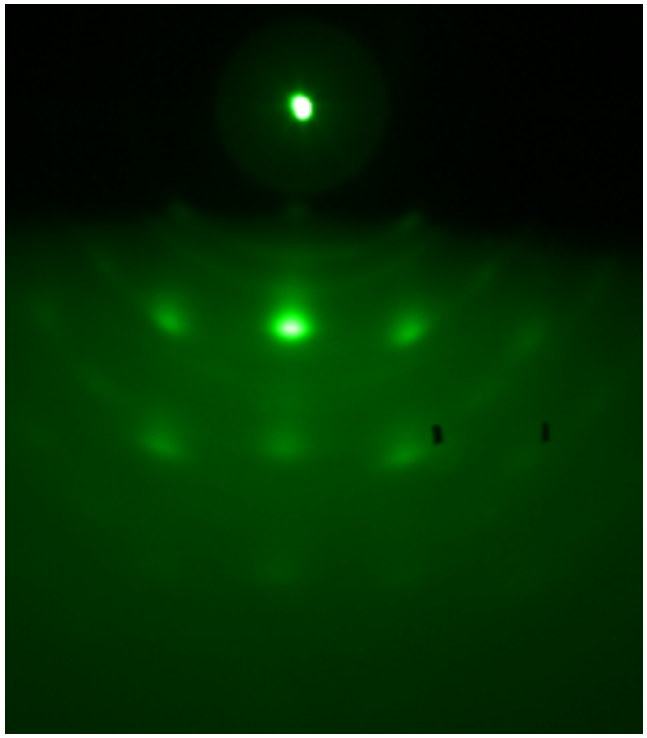
RHEED Station

Movie of 0.8 meter moving IBAD tape

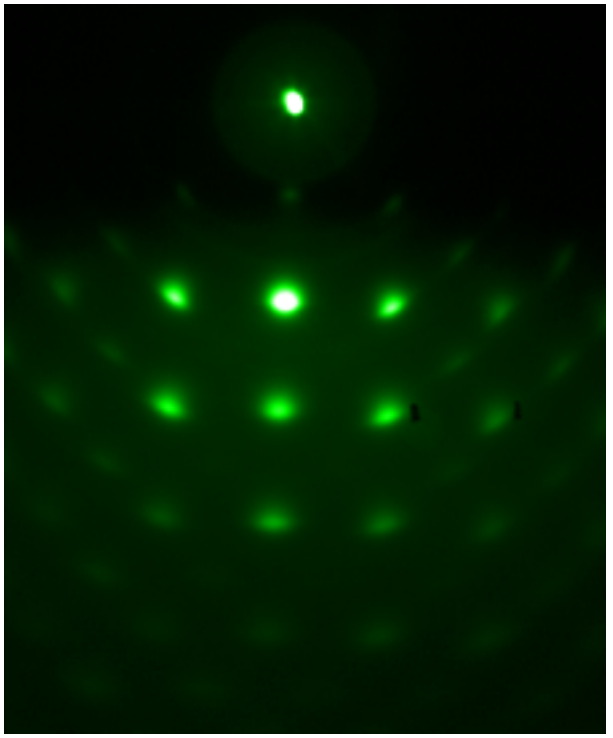


IBAD and epi-MgO deposited continuously
RHEED used for quality control

Buffer Layer Deposition

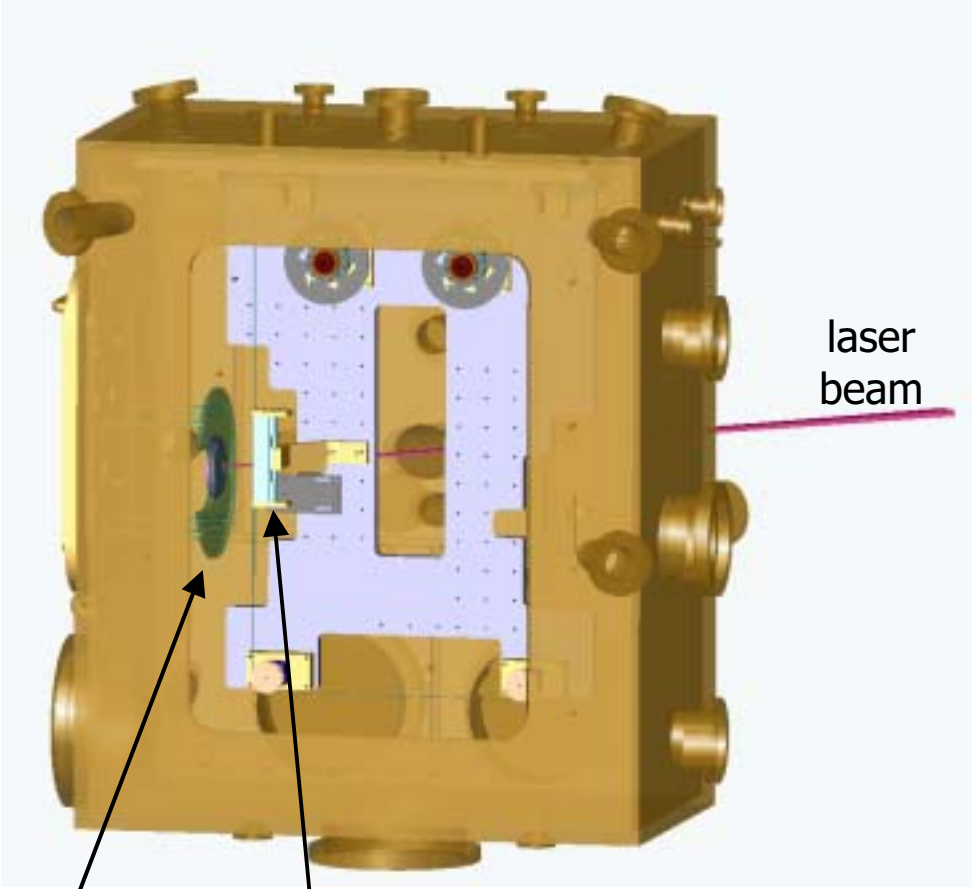


YSZ on MgO



CeO_2 on YSZ

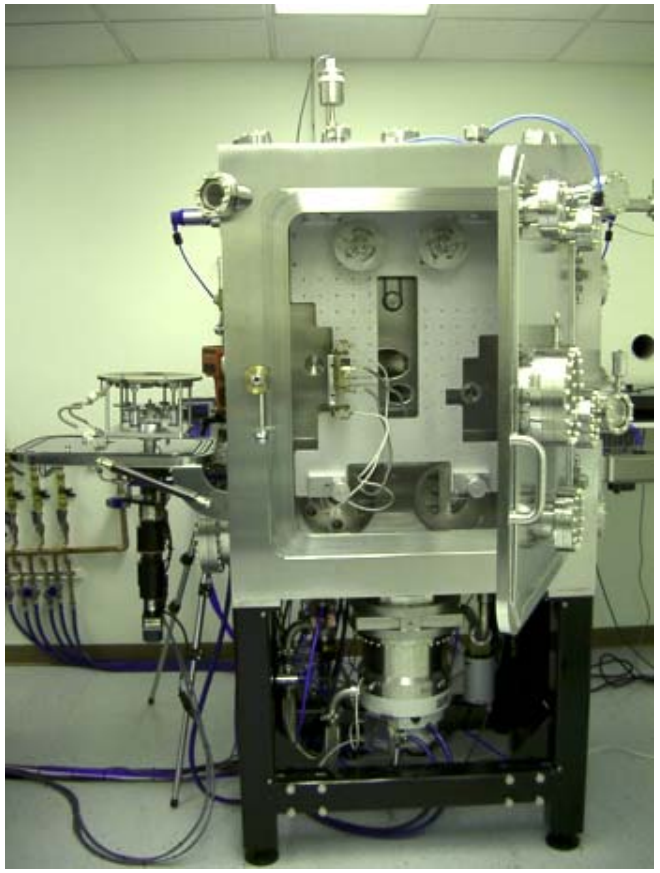
Pulsed-Laser Deposition Chamber



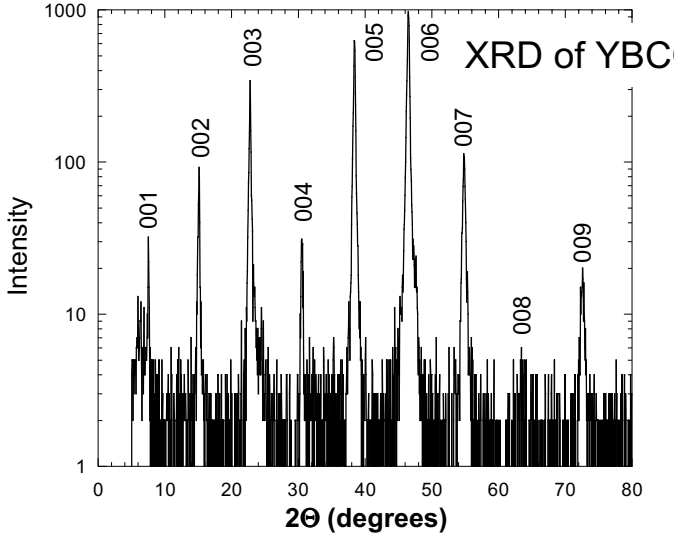
- Four 4” targets for deposition of a variety of oxide layers
- Quartz lamp heater allows for heating of tape as it continuously moves through the PLD zone
- *In-situ* adjustment of tape position with respect to laser plume
- Silver deposition integrated

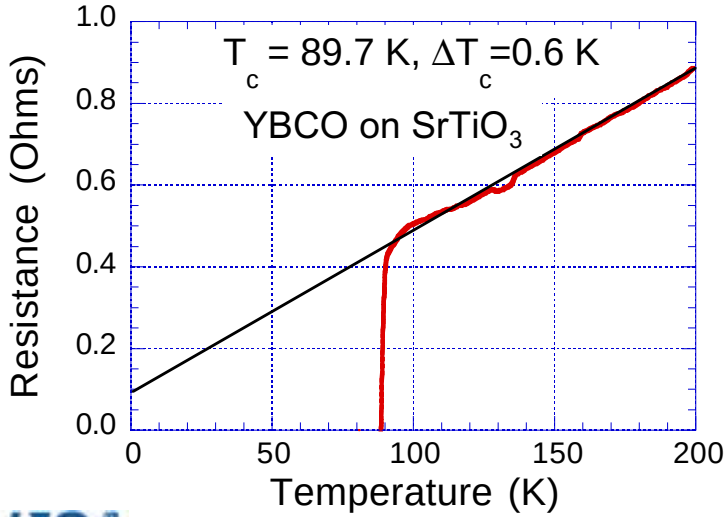
Pulsed-Laser Deposition Chamber

- Relatively large chamber for PLD (4'x3.5'x2')
- Easy access via front and side doors
- 4000 l/s pumping speed, chamber pumps down in 1 hour
- Industrial 200 W XeCl (308 nm) laser is used for PLD



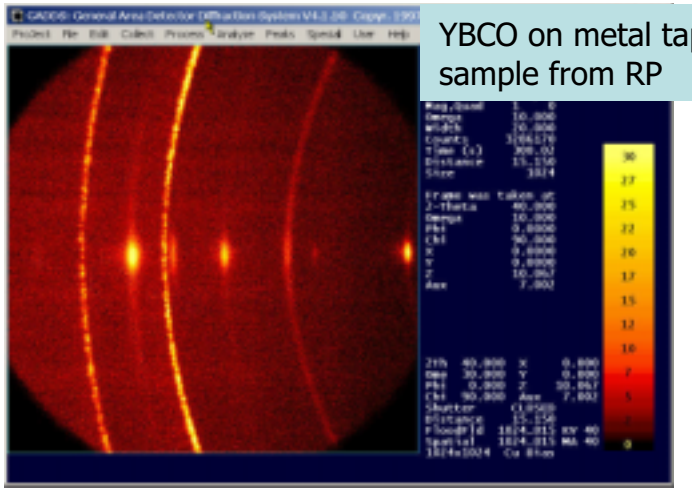
PLD Results





- High-quality YBCO deposited on single-crystal substrates
- Continuous deposition of YBCO on tape demonstrated
- Process is being optimized for deposition conditions and buffer layer architecture

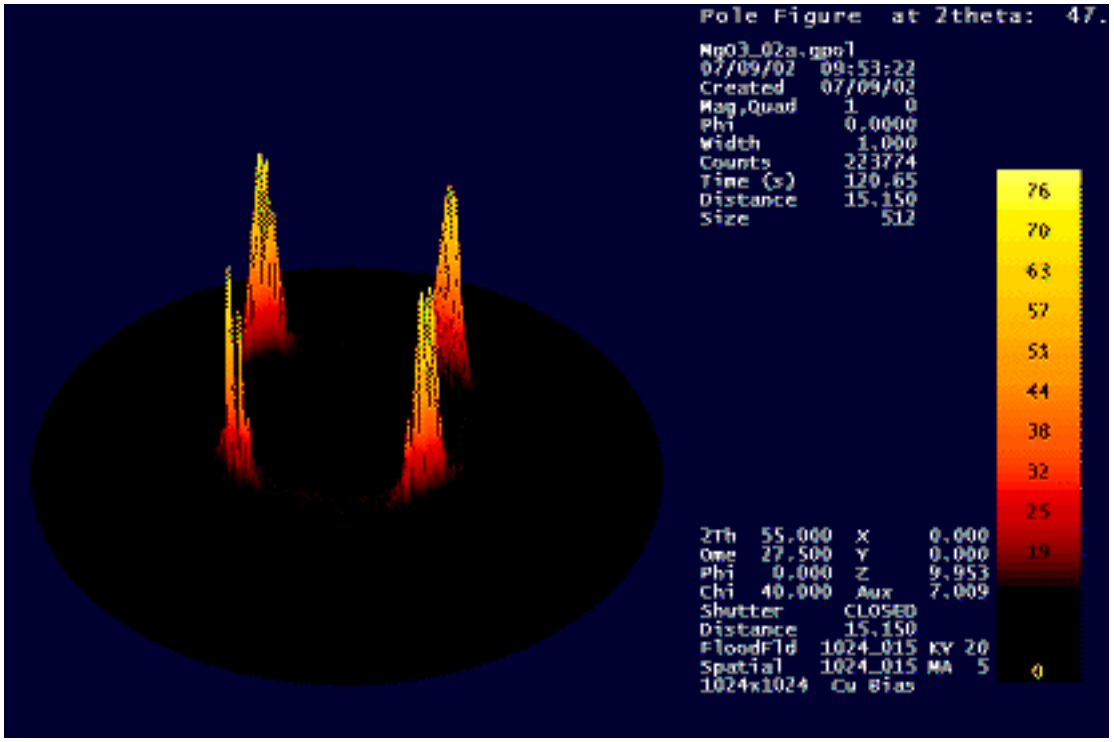
X-ray Diffraction Apparatus



YBCO on metal tape sample from RP

- Bruker D8 Discover XRD
- 2D Position Sensitive Detector (GADDS)
- x,y stage with a minimum 10 μm spot size
- Capability to include reel-to-reel sample transport

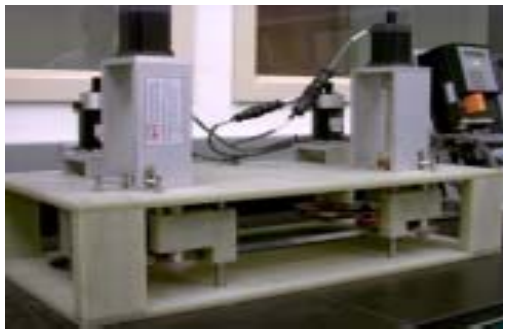
XRD Texture Analysis: Pole Figures

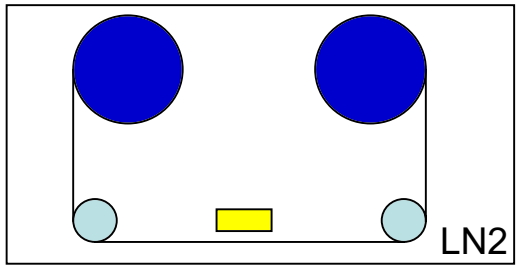


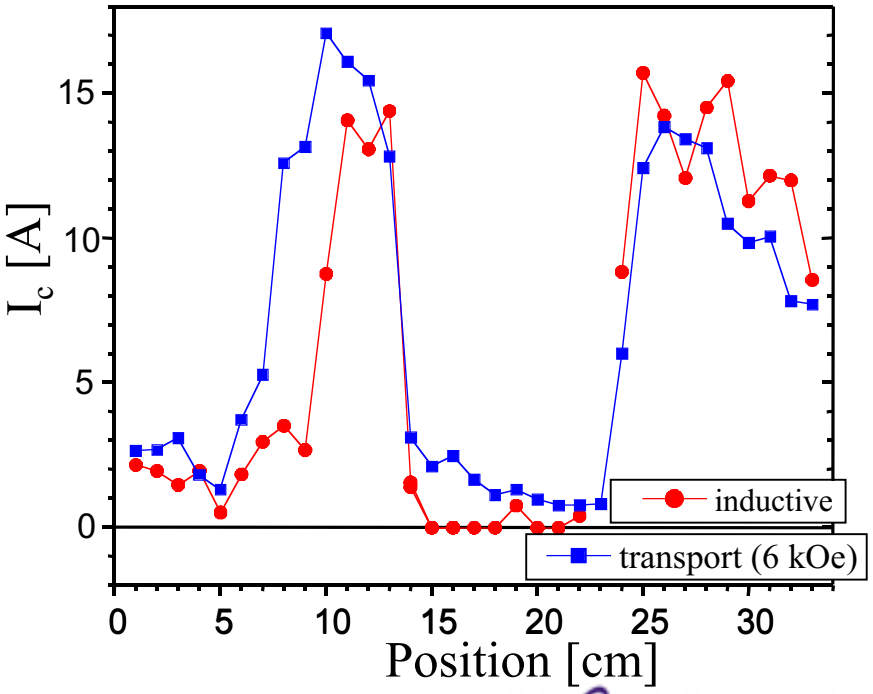
- Sample prepared in the IBAD system at the RP
- CeO_2 550 Å layer on top of YSZ buffered IBAD-MgO on metal tape
- 12° FWHM in-plane texture

Low-Temperature Electrical Measurements

- Reel-to-reel set up for low-T electrical measurements (contact and non-contact)
- Non-contact J_c measurement
  - ac (2 kHz) inductive technique measures first and third harmonics
  - calibration against transport
- Data collection to be integrated with the sample preparation database





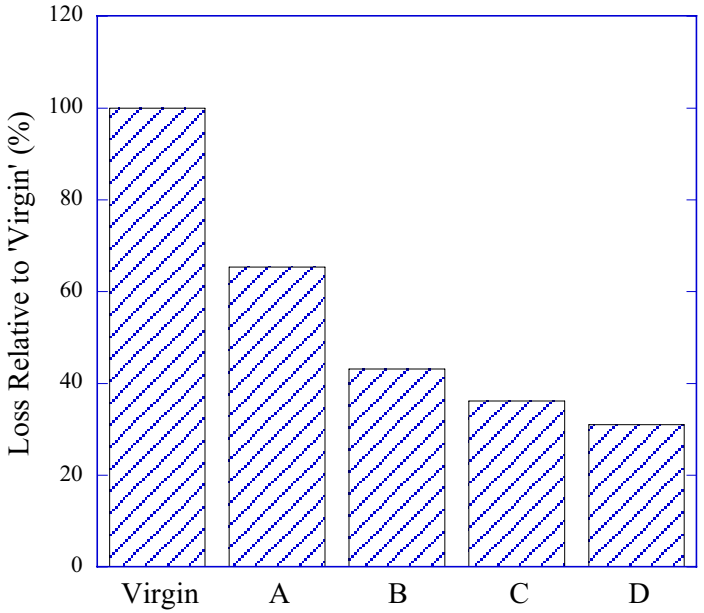


Reduction of ac Loss in Coated Conductor

- ac losses of coated conductor will be important in applications
- Near I_c comparable to BSCCO-2223

  e.g. I_c = 60A, peak current = 90% I_c

  Loss = 0.3mJ/cycle/m ('virgin' value)
- Aim to reduce losses without increasing $/kA/m
- 'Manage' entry of magnetic field into CC in a number of different ways (A – D).
- Reduce losses due to ac transport currents to approx: 30% of 'virgin' coated conductor
- Patent application submitted recently



FY2002 Performance

2002 PLAN (presented at the 2001 Peer Review):

✓ • Set up the Coated Conductor Labs at the Research Park

✓ • Demonstrate working continuous processes for coated conductors

Tape polishing, IBAD and PLD demonstrated in continuous processes

✓ • Demonstrate *in-situ* monitoring/diagnostics capability

RHEED implemented and demonstrated in use

✓ • ac-loss measurements on coated conductors

✓ • Establish an open environment for research and a user facility where various parties can work together

✓ • Establish meaningful partnerships with interested parties

CRADA's, commitments from external partners

FY2002 Results

- Labs set up for long-length (reel-to-reel) coated conductor fabrication and characterization:
  - Tape electropolishing @ 30 m/hr with < 1 nm roughness over 5 µm
  - IBAD: multiple meters of IBAD-MgO template prepared, 12° in-plane texture, 2.7° out-of-plane, @ 6 m/hr; buffer layers deposited in the same system at similar speeds
  - PLD: YBCO deposited continuously and on various substrates
  - Low-temperature electrical testing: non-contact J_c measurement
- *In-situ* RHEED used for process optimization and quality control
- Combinatorial approach used for optimizing processes
- New x-ray diffraction apparatus with area detector installed and used
- Ways to reduce ac losses of coated conductors in a field were implemented

Research Integration

- CRADA's established with IGC and DuPont
- ANL, BNL, ORNL committed to working at the Research Park
- LBL, SNL, U Wisconsin, Stanford, U Kansas, WPAFB, ASC, and 3M have expressed interest in collaborating at the Research Park
- Magnetic separator SPI with DuPont
  - DuPont postdoc stationed at the Research Park
- Established environment for new partnerships with industry, universities and national labs
  - Opportunities for user facility agreements
  - Opportunities for interaction and sample supply for the MURI Program (esp. scanning techniques for local dissipation measurements)

FY2003 Plans

- Complete the system integration and process control on fabrication systems - set up for ease-of-use and sample tracking
- Achieve performance of IBAD-MgO coated conductors: MgO in-plane texture < 8° and I_c >50 A on 1-cm wide, long-length (> 5 m) tape
- Add ion scattering capability to *in-situ* diagnostics
- Establish a User Facility Program with a User Advisory Committee, incorporating at least 5 outside members
- Establish an applications testing lab: 5000 A dc and ac (variable frequency 30 to 800 Hz)
- Fabricate a 10 m CC coil and a 1000 A one-meter long CC cable and evaluate their ac and dc performance

Conclusions

- Expanded effort at Los Alamos is an aggressive program for Coated Conductor scaled-up fabrication with the goals of:
  - **High-throughput** sample preparation and characterization in **continuous** reel-to-reel processing
  - Achieving longer lengths of coated conductors
  - *In-situ* and *real-time* process diagnostics capability
- Tape fabrication processes are currently operational
- Applications lab is being set up for testing and evaluation of coated conductors and prototype applications
- User facility, training and sample exchange will be available in the next year